other polarized beams, which are polarized in a different direction, in a process of converting randomly polarized beams emitted from a light source into the same type of polarized beams.

In order to solve the above problems, a polarizing conversion device in accordance with the present invention comprises a polarizing separation element that has a polarizing separation plane for separating P and S polarized beams by transmitting one of the polarized beams therethrough and reflecting the other polarized beam, and a reflecting plane disposed substantially parallel with the polarizing separation plane to reflect the polarized beam reflected by the polarizing separation plane toward the emergent direction of the polarized beam transmitted through the polarizing separation plane, and a selective phase plate located on the light emergent side of the polarizing separation element to align the polarization direction of one of the S and P polarized beams separated by the polarizing separation element with the polarization direction of the other polarized beam, wherein at least one of a shading means and an optical attenuating means for preventing light from directly entering the reflecting plane is provided on the light incident side of the polarizing separation element.

The above structure enables the polarizing conversion device of the present invention to effectively prevent or restrict a phenomenon in which other polarized beams polarized in a different direction mix into polarized beams of almost the same type polarized in the same direction. Therefore, it is possible to generate specific polarized beams with an extremely high efficiency.

In the above-mentioned polarizing conversion device, it is preferable that the shading means or the optical attenuating means and the polarizing separation element are integrated. It is therefore possible to reduce light losses at an interface, and to thereby provide a polarizing conversion device having a high light use efficiency.

The shading means may be formed of a reflecting plate. When the shading means is formed of a reflecting plate, it does not absorb much light, and therefore, does not generate much heat. Consequently, it is possible to prevent peripheral optical elements from being thermally influenced by heat generation of the shading means. This is effective particularly when the selective phase plate is made of an organic substance that is not heat-resistant.

Furthermore, when the shading means and the polarizing separation element are integrated, the shading means may be formed of a reflecting film that is formed on the light incident surface of the polarizing separation element. Such a structure also provides similar advantages as those achieved in the situation wherein the shading means is formed of a reflecting plate. The reflecting film may be formed of a dielectric multilayer film, or a thin film of metal having high reflectivity, such as silver or aluminum.

Still furthermore, the optical attenuating means in the polarizing conversion device may be formed of a light diffusing plate. When the optical attenuating means is formed of a light diffusing plate, it is possible to reduce the cost of the polarizing conversion device.

When the shading means and the polarizing separation element are integrated, the optical attenuating means may be formed of a light diffusing surface formed on the light incident surface of the polarizing separation element. Such a structure also provides similar advantages as those achieved in the situation wherein the optical attenuating means is formed of a light diffusing plate. The light diffusing surface may be formed by roughening a specific region on the light incident surface of the polarizing separation element.

A polarizing illumination device in accordance with the present invention comprises a light source, a first optical element for separating a light beam emitted from the light source into a plurality of intermediate beams, and a second optical element disposed near the position where the intermediate beams converge, wherein the second optical element has a condenser lens array that includes a plurality of condenser lenses for respectively condensing the intermediate beams, a polarizing separation element for spatially separating each of the intermediate beams into an S polarized beam and a P polarized beam, a selective phase plate for aligning the polarization direction of one of the S and P polarized beams separated by the polarizing separation element with the polarization direction of the other polarized beam, and a superimposing lens for superimposing the polarized beams, the polarizing separation element has a polarizing separation plane for separating the P and S polarized beams by transmitting one of the polarized beams therethrough and reflecting the other polarized beam and a reflecting plane disposed substantially parallel with the polarizing separation plane to reflect the polarized beam reflected by the polarizing separation plane toward the emergent direction of the polarized beam transmitted through the polarizing separation plane, and at least one of a shading means and an optical attenuating means for preventing each of the intermediate beams from directly entering the reflecting plane is interposed between the first optical element and the polarizing separation element.

By adopting the above structure, the polarizing illumination device in accordance with the present invention can effectively prevent or restrict a phenomenon in which other polarized beams polarized in a different direction mix into polarized beams of almost the same type polarized in the same direction. Therefore, it is possible to obtain as illumination light polarized beams with a considerably high degree of polarization.

According to the above structure, an incident beam is initially separated into a plurality of intermediate beams and the intermediate beams are finally superimposed on one illumination region. Therefore, even if the intensity distribution of the incident beam is very imbalanced in the cross section thereof, it is possible to use as illumination light polarized beams that are uniform in brightness and color. Furthermore, even when each of the intermediate beams cannot be separated into a P polarized beam and an S polarized beam that have equal light intensity and spectral characteristics, and even when the light intensity and the spectral characteristics of one of the polarized beams changes in a process of aligning the polarization directions of the polarized beams, it is possible to use as illumination light polarized beams that are uniform in brightness and color.

In addition, a plurality of polarized beams brought into almost one type of polarization state are gathered as a whole, superimposed on one illumination region, and form a large bundle of beams. Since the polarized beams of this large bundle of beams themselves do not accompany a beam component that has a large divergence angle, illumination with these light beams secures a high illumination efficiency.

The light source may include a light source lamp and a reflector. A metal halide lamp, a xenon lamp, a halogen lamp, and similar devices may be used as the light source lamp, and a parabolic reflector, an elliptic reflector, a spherical reflector, and similar devices may be used as the reflector.

In the above polarizing illumination device, the shading means or the optical attenuating means may be placed at any pnsition between the pnlarizing separation element and the first optical element. However, if the shading means or the optical attenuating means is integrated with the polarizing separatinn element, it is pnssible tn reduce light loss at the interface and to thereby provide a polarizing illumination device having a high light use efficiency. Furthermore, the second optical element can be formed in one piece by integrating the shading means or the optical attenuating means and the polarizing separation element, and in that situation, the second nptical element can be made to be cnnsiderably compact.

The shading means or the optical attenuating means may be integrated with the condenser lens array. This prnvides similar advantages to those nf the situation in which the shading means or the optical attenuating means is integrated with the polarizing separation element. Furthermore, in this situation, when the cnndenser lens array integrated with the shading means or the optical attenuating means is placed spatially apart from other optical elements to form the second optical element (for example, the polarizing separation element and the selective phase plate), even if the shading means or the optical attenuating means generates heat due to light absorption, it is possible to prevent the other nptical elements from being thermally influenced by the heat generation.

In the above polarizing illumination device, the shading means may be formed of a reflecting plate. When the shading means is formed of a reflecting plate, it does not absorb much light, and therefore, does not generate much heat. Consequently, it is possible to prevent peripheral nptical elements from heing thermally influenced by heat generation of the shading means. This is effective particularly when the selective phase plate is made nf an organic substance that has small heat resistance. Moreover, when the shading means is formed of a reflecting plate, light reflected hy the reflecting plate is allowed to return tn the light source once, to be reflected again hy the reflector at the light source, and to enter the polarizing separation element again. Therefore, it is possible to effectively use the light from the light source withnut waste.

Furthermore, when the shading means is integrated with the polarizing conversion device and the condenser lens array, the shading means may be formed of a reflecting film that is formed on the light incident surface of the polarizing separation element or the light emergent surface of the condenser lens array. Such a structure also prnvides similar advantages tn those of the situation in which the shading means is formed of a reflecting plate. The reflecting film may he formed of a dielectric multilayer film, nr a thin film of metal having high reflectivity, such as silver or aluminum.

In the ahove polarizing illumination device, the optical attenuating means may be formed of a light diffusing plate. When the optical attenuating means is formed of a light diffusing plate, it is possihle to achieve cost reduction of the polarizing illumination device.

When the optical attenuating means is integrated with the polarizing conversion device or the condenser lens array, it may be formed of a light diffusing surface formed on the light incident surface of the polarizing separatinn element or the light emergent surface nf the condenser lens array. Such a structure also provides similar advantages as those achieved in the situation in which the optical attenuating means is formed nf a light diffusing plate, and the situation in which the optical diffusing plate is integrated with the polarizing separatinn element nr the cnndenser lens array. The light diffusing surface may be formed by roughening a specific region on the light incident surface of the polarizing separation element nr the light emergent surface of the condenser lens array.

A display apparatus in accordance with the present invention comprises a light source, a first optical element for separating a light heam emitted from the light source into a plurality of intermediate beams, a second optical element located near the position where the intermediate beams converge, and a mndulating device for modulating a light heam emitted from the second optical element, wherein the second optical element has a cnndenser lens array that includes a plurality of condenser lenses for respectively condensing the intermediate beams, a polarizing separation element for spatially separating each nf the intermediate beams into an S polarized heam and a P polarized beam, a selective phase plate for aligning the polarization direction of one of the S and P polarized beams separated by the pnlarizing separation element with the polarization direction of the other polarized beam, and a superimposing lens for superimposing the polarized beams, the polarizing separatinn element has a polarizing separation plane for separating the P and S polarized beams by transmitting one of the polarized beams therethrough and reflecting the other polarized beam and a reflecting plane dispnsed substantially parallel with the polarizing separation plane to reflect the polarized beam reflected by the polarizing separation plane toward the emergent direction nf the pnlarized beam transmitted through the polarizing separation plane, and at least one of a shading means and an optical attenuating means for preventing each of the intermediate beams fmm directly entering the reflecting plane is interposed between the first optical element and the polarizing separation element.

By adopting the above structure, the display apparatus in accordance with the present invention can effectively prevent a phenomenon in which other polarized heams polarized in a different direction mix into polarized beams nf almost the same type polarized in the same direction. Therefore, when a polarizing plate is used to ohtain a required polarized heam modulated by the modulating device, it is possible tn prevent the increase in temperature nf the polarizing plate caused by absorption of an unnecessary polarized beam, and to substantially simplify and miniaturize a cnnling device for conling the polarizing plate. A liquid crystal device may he used as the modulating device.

According to the above structure, an incident beam is initially separated into a plurality of intermediate beams and the intermediate beams are finally superimposed on the modulating device. Therefore, even if the light distributinn of the light emitted from the light source is very imhalanced in the cross section thereof, it is possihle to ohtain as illumination light polarized beams that are unifnrm in brightness and color. Cnnsequently, it is possible to achieve a compact display apparatus capahle of producing a display that is hright and uniform in brightness and color.

A projection display apparatus in accordance with the present invention comprises a light source, a first optical element for separating a light beam emitted from the light source into a plurality nf intermediate beams, a second optical element disposed near the position where the intermediate heams converge, a modulating device for modulating a light beam emitted from the second optical element, and a projection nptical system for projecting the light heam modulated hy the modulating device onto a projection plane, wherein the second optical element has a condenser lens

array that includes a plurality of condenser lenses for respectively condensing the intermediate beams, a polarizing separation element for spatially separating each of the intermediate beams into an S polarized beam and a P polarized beam, a selective phase plate for aligning the polarization direction of one of the S and P polarized beams separated by the polarizing separation element with the polarization direction of the other polarized beam, and a superimposing lens for superimposing the polarized beams, the polarizing separation element has a polarizing separation plane for separating the P and S polarized beams by transmitting one of the polarized beams therethrough and reflecting the other polarized beam and a reflecting plane located almost in parallel with the polarizing separation plane to reflect the polarized beam reflected by the polarizing separation plane toward the emergent direction of the polarized beam transmitted through the polarizing separation plane, and at least one of a shading means and an optical attenuating means for preventing each of the intermediate beams from directly entering the reflecting plane is interposed between the first optical element and the polarizing separation element.

By adopting the above structure, the projection display apparatus of the present invention can effectively prevent a phenomenon in which other polarized beams polarized in a different direction mix into polarized beams of almost the same type polarized in the same direction. Therefore, when a polarizing plate is used to obtain a required polarized beam to be modulated by the modulating device, it is possible to prevent the increase in temperature of the polarizing plate caused by absorption of an unnecessary polarized beam, and to substantially simplify and reduce the size of a cooling device for cooling the polarizing plate. A liquid crystal device may be used as the modulating device.

According to the above structure, an incident beam is initially separated into a plurality of intermediate beams and the intermediate beams are finally superimposed on the modulating device. Therefore, even if the intensity distribution of the light emitted from the light source is very imbalanced in the cross section thereof, it is possible to obtain as illumination light polarized beams that are uniform in brightness and color. Consequently, it is possible to achieve a compact display apparatus capable of producing a display that is bright and uniform in brightness and color.

The projection display apparatus further comprises a color light separation means for separating the light beam emitted from the second optical element into a plurality of colored lights, a plurality of modulating devices for respectively modulating the colored lights, and a colored light synthesizing means for synthesizing the colored lights modulated by the modulating devices, wherein a synthesized beam synthesized by the colored light synthesizing means is projected onto the projection plane through the projection optical system. Since exclusive modulating devices can be placed respectively for more than two separated colored lights, it is possible to achieve a compact projection display apparatus capable of projecting and displaying a color image that is bright and has a high color reproducibility and a high resolution.

In the above projection display apparatus, the modulating device may be formed of a reflection-type liquid crystal device. In general, the reflection-type liquid crystal device provides the advantage of easily obtaining a relatively high aperture ratio even if pixel density is increased. Therefore, adopting of the above structure makes it possible to achieve a compact projection display apparatus capable of projecting and displaying a color image that is bright and has a high color reproducibility and a high resolution.



## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic structural view of an optical system in a polarizing illumination device according to a first embodiment of the present invention.

FIG. 2 is a perspective view of a first optical element according to the first embodiment of the present invention.

FIG. 3 is a perspective view of a shading plate according to the first embodiment of the present invention.

FIG. 4 is a perspective view of a polarizing separation unit array according to the first embodiment of the present invention.

FIG. 5 is a view showing the operation of a polarizing separation unit according to the first embodiment of the present invention.

FIG. 6 is a perspective view of a shading plate according to a first modification of the first embodiment of the present invention.

FIG. 7 is a perspective view of a shading plate according to a second modification of the first embodiment of the present invention.

FIG. 8 is a perspective view of a polarizing separation unit array according to a third modification of the first embodiment of the present invention.

FIG. 9 is a perspective view of a condenser lens array according to a fourth modification of the first embodiment of the present invention.

FIG. 10 is a perspective view of a shading plate according to a fifth modification of the first embodiment of the present invention.

FIG. 11 is a schematic structural view showing the principal part of an optical system in a display apparatus according to a second embodiment of the present invention, in which the polarizing illumination device shown in FIG. 1 is incorporated.

FIG. 12 is a schematic structural view showing the principal part of an optical system in a projection display apparatus according to a third embodiment of the present invention, in which the polarizing illumination device shown in FIG. 1 is incorporated.

FIG. 13 is a schematic structural view showing the principal part of an optical system in a projection display apparatus according to a fourth embodiment of the present invention, in which the polarizing illumination device shown in FIG. 1 is incorporated.

FIG. 14 is a schematic structural view showing the principal part of an optical system in a modification of the projection display apparatus according to the fourth embodiment of the present invention, in which the polarizing illumination device shown in FIG. 1 is incorporated.

FIG. 15 is a schematic structural view of a polarizing optical system disclosed in Japanese Unexamined Patent Publication No. 7-294906.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Modes for carrying out the present invention will be described below in connection with embodiments and with reference to the drawings. In the following embodiments, three directions orthogonal to one another are, for the sake of convenience, taken as an X direction (lateral direction), a Y direction (longitudinal direction), and a Z direction, unless otherwise stated. Although S polarized beams are obtained as the same type of polarized beams of the same type from randomly polarized beams in any of the embodiments, of

course, P polarized beams may be obtained. Moreover, in the embodiments that will be described below, sections that have substantially the same functions and structure are denoted by the same numerals, and a description thereof is omitted.

First Embodiment

FIG. 1 is a schematic structural plan view of the principal part of a polarizing illumination device according to a first embodiment. FIG. 1 is a plan view in the XZ plane which passes through the center of a first optical element 200 which will be described later. The polarizing illumination device 1 of this embodiment generally comprises a light source section 10 and a polarized light generating device 20 that are arranged along a system optical axis L. Light beams emitted from the light source section 10 and polarized in random directions (hereinafter referred to as randomly polarized beams) are converted by the polarized light generating device 20 into the same type of polarized beams that are polarized in almost the same direction, and directed to an illumination region 90.

The light source section 10 generally comprises a light source lamp 101 and a parabolic reflector 102. Light radiated from the light source lamp is reflected by the parabolic reflector 102 in one direction, and made incident on the polarized light generating device 20 in the form of almost parallel light beams. The light source section 10 is placed so that a light source optical axis R thereof is shifted in parallel from the system optical axis L by a required distance D in the X direction.

The polarized light generating device 20 comprises a first optical element 200 and a second optical element 300.

The first optical element 200, as outwardly shown in FIG. 2, includes a matrix of a plurality of beam splitting lenses 201 each having a rectangular outline in the XY plane. The positional relationship between the light source section 10 and the first optical element 200 is set so that the light source optical axis R aligns with the center of the first optical element 200. Light that is incident on the first optical element 200 is split into a plurality of intermediate beams 202 by each beam splitting lens 201, and simultaneously, the same number of condensed images 203 as that of the beam splitting lenses are formed, by a condensing action of the beam splitting lenses, at positions in a plane (the XY plane in FIG. 1) perpendicular to the system optical axis L, where the intermediate beams converge. The outline of each beam splitting lens 201 in the XY plane is set so that it is similar to that of the illumination region 90. Since it is assumed that the illumination region in this embodiment extends laterally in the X direction in the XY plane, the outline of the beam splitting lens 201 in the XY plane is also extended laterally.

The second optical element 300 is a complex that generally includes a condenser lens array 310, a shading plate 370, a polarizing separation unit array 320, a selective phase plate 380, and a superimposing lens 390, and is placed in a plane (the XY plane in FIG. 1) perpendicular to the system optical axis L near the positions where the condensed images 203 are formed by the first optical element 200. When the light beams that are incident on the first optical element 200 are extremely parallel, the condenser lens array 310 does not have to be included in the second optical element. The second optical element 300 operates to spatially separate each intermediate beam 202 into a P polarized beam and an S polarized beam, aligns the polarization direction of one polarized beam and that of the other polarized beam, and directs the beams polarized in substantially the same direction to one point in the illumination region 90.



The condenser lens array 310 has almost the same structure as the first optical element 200, that is, it comprises a matrix of the same number of condenser lenses 311 as that of the beam splitting lenses 201 of the first optical element 200. The condenser lens array 310 operates to condense and direct each intermediate beam to a specific position in the polarizing separation unit array 320. Therefore, it is preferable to optimize the lens properties of the condenser lenses in accordance with the properties of the intermediate beams 202 formed by the first optical element 200, and considering that the ideal placement of the principal ray of the light incident on the polarizing separation unit array 320 is parallel with the system optical axis L. Generally, in consideration of cost reduction and easy design of the optical system, an element entirely identical with the first optical element 200 may be used as the condenser lens array 310, or a condenser lens array that includes condenser lenses similar in shape to the beam splitting lenses 201 in the XY plane may be used. Therefore, in this embodiment, the first optical element 200 is used as the condenser lens array 310. The condenser lens array 310 may be placed apart from the shading plate 370 and the polarizing separation unit array 320 (on the side closer to the first optical element 200).

The shading plate 370, as outwardly shown in FIG. 3, includes an array of a plurality of shading surfaces 371 and a plurality of open surfaces 372. The shading surfaces 371 and the open surfaces 372 are arranged in a manner corresponding to the arrangement of polarizing separation units 330 which will be described later. Four broken lines parallel with the X axis on the shading plate 370 in FIG. 3 are drawn to explain the correspondence to the polarizing separation unit array which will be described later. This also applies to a reflecting plate 373 shown in FIG. 6 and a light diffusing plate 376 shown in FIG. 7. Light beams that are incident on the shading surfaces 371 of the shading plate 370 are blocked, and light beams that are incident on the open surfaces 372 pass through the shading plate 370 unchanged. Therefore, the shading plate 370 operates to control the light beams in accordance with the positions thereon where the light beams transmit, and the shading surfaces 371 and the open surfaces 372 are arranged so that the condensed images 203 are respectively formed by the first optical element 200 only on polarizing separation planes 331 of the polarizing separation units 330 which will be described later. A flat transparent member, such as a glass plate, partially provided with opaque films made of chrome, aluminum or similar materials as in this embodiment, an opaque flat plate, such as an aluminum plate, provided with open sections, and similar structures may be used as the shading plate 370. Particularly, when opaque films are used, even if they are directly formed on the condenser lens array 310 or the polarizing separation unit array 320, which will be described later, it is possible to provide similar functions.

The polarizing separation unit array 320, as outwardly shown in FIG. 4, includes a matrix of a plurality of polarizing separation units 330. The polarizing separation units 330 are arranged corresponding to the lens properties and arrangement of the beam splitting lenses 201 which form the first optical element 200. Since the first optical element 200 include the concentric beam splitting lenses 201 which all have the same lens properties and are arranged in a rectangular matrix in this embodiment, the polarizing separation unit array 320 also includes all the same polarizing separation units 320 which are arranged in the same direction and in a crossed matrix. When the polarizing separation units aligned in the Y-direction column are of all the same type, it is preferable that the polarizing separation unit array 320

include polarizing separation units which are long in the Y direction and are arranged in the X directioo, which is advantageous in reducing light losses at the interfaces between the polarizing separation units and in reducing the production cost of the polarizing separation unit array.

Each polarizing separation unit 330 is, as outwardly shown in FIG. 5, a member shaped like a quadrangular prism and provided with a polarizing separation plane 331 and a reflecting plane 332 therein, and operates to spatially separate each intermediate light beam, that enters the polariziog separation unit, into a P polarized beam and an S polarized beam. The outline of the polarizing separation unit 330 in the XY plane is similar to that of the beam splitting lens 201 in the XY plane, that is, it is shaped like a rectangle which is extended laterally. Therefore, the polarizing separation plane 331 and the reflecting plane 332 are placed so that they are arranged in the lateral direction (the X direction). The polarizing separation plane 331 and the reflecting plane 332 are placed so that the polarizing separation plane 331 inclines at about 45° with respect to the system optical axis L, the reflecting plane 332 is parallel to the polarizing separation plane 331. The projection area of the polarizing separation plane 331 in the XY plane (that is equal to the area of a P emergent surface 333 described later) and the projection area of the reflecting plane 332 in the XY plane (that is equal to the area of an S emergent surface 334 described later) are equal to each other. Therefore, in this embodiment, a width Wp of a region in the XY plane, where the polarizing separation plane 331 exists, and a width Wm of a region in the XY plane, where the reflecting plane 332 exists, are equally set so that they are each half a width W of the polarizing separation unit in the XY plane. In general, the polarizing separation plane 331 may be made of a dielectric multilayer film, and the reflecting plane 332 may be made of a dielectric multilayer film or an aluminum film.

Light incident on the polarizing separation unit 330 is separated by the polarizing separation plane 331 into a P polarized beam 335 that transmits through the polarizing separation plane 331 without changing its direction of travel and an S polarized beam 336 that is reflected by the polarizing separation plane 331 and changes its direction of travel toward the adjoining reflecting plane 332. The P polarized beam 335 is emitted from the polarizing separation unit through the P emergent surface 333 unchanged, and the S polarized beam 336 again changes its direction of travel at the reflecting plane 332, and is emitted from the polariziog separation unit through the S emergent surface 334 substantially parallel with the P polarized beam 335. Therefore, randomly polarized beams incident on the polarizing separation unit 330 are separated into two types of polarized beams polarized in different directions, the P polarized beam 335 and the S polarized beam 336, and are emitted substantially the same direction from different sections of the polarizing separation unit (the P emergent surface 333 and the S emergent surface 334). Since the polarizing separation unit has the above-mentioned functions, it is necessary to lead each intermediate beam 202 to the region of the polarizing separation unit 330 where the polarizing separation plane 331 exists. Accordingly, the positional relationship between each polarizing separation unit 330 and each condenser lens 311 and the lens properties of the condenser lens 311 are set so that the intermediate beam enters the center of the polarizing separation plane in the polarizing separation unit. Particularly, in this embodiment, the condenser lens array 310 is placed offset from the polarizing separation unit array 320 by a distance D, which corresponds to ¼ of the width W of the polarizing separation unit, in the X direction so that the center axis of each condenser lens aligns with the center of the polarizing separation plane 331 in each polarizing separation unit 330.



Any polarizing separation unit array may be used as long as the above-mentioned polarizing separation planes and reflecting planes are regularly formed therein, and it is not always necessary to use the above-mentioned polarizing separation units as basic constituents. Herein, the polarizing separation units are discussed as constituents only to explain the function of the polarizing separation unit array.

Description will be made again with reference to FIG. 1.

The shading plate 370 is interposed between the polarizing separation unit array 320 and the condenser lens array 310 so that the center of each open surface 372 of the shading plate 370 is substantially aligned with the center of the polarizing separation plane 331 of each polarizing separation unit 330. The opening width of the open surface 372 (the opening width in the X direction) is set about half the width W of the polarizing separation unit 330. As a result, since intermediate beams are previously blocked by the shading surface 371 of the shading plate 370, there are few beams that directly enter the reflecting plane 332 without passing through the polarizing separation plane 331, and most of the light beams passed through the open surface 372 of the shading plate 370 enter only the polarizing separation plane 331. Consequently, because of such placement of the shading plate 370, few light beams directly enter the reflecting planes 332 and enter the adjoining polarizing separation planes 331 through the reflecting planes 332 in the polarizing separation unit.

The selective phase plate 380, in which λ/2 phase plates 381 are regularly arranged, is placed on the emergent side of the polarizing separation unit array 320. That is, the λ/2 phase plates 381 are respectively placed only at the P emergent surfaces 333 of the polarizing separation units 330 which form the polarizing separation unit array 320, and no λ/2 phase plates 381 are placed at the S emergent surfaces 334 (see FIG. 5). According to such an arrangement of the λ/2 phase plates 381, when P polarized beams emitted from the polarizing separation units 330 respectively pass through the λ/2 phase plates 381, they are converted into S polarized beams by a polarization direction rotating action. On the other hand, since S polarized beams emitted from the S emitting surfaces 334 do not pass through the λ/2 phase plates 381, they do not change their polarization direction and pass through the selective phase plate 380 unchanged. In summary, intermediate beams polarized in random directions are converted into polarized beams of the same type (in this case, the S polarized beams) by the polarizing separation unit array 320 and the selective phase plate 380.

The superimposing lens 390 is placed on the emitting side of the selective phase plate 380. The light beams, which are converted into the S polarized beams by the selective phase plate 380, are directed to the illumination region 90 by the superimposing lens 390 and superimposed on the illumination region. The superimposing lens 390 is not limited to a single lens member, and it may be an assembly of a plurality of lenses like the first optical element 200.

To summarize the operations of the second optical element 300, the intermediate beams 202 separated by the first optical element 200 (that is, image planes cut out by the beam splitting lenses 201) are superimposed on the illumination area 90 by the second optical element 300. At the same time, the intermediate beams, which are randomly polarized beams, are spatially separated into two types of polarized beams polarized in different directions by the

polarizing separation unit array 320 placed in the path, and converted into substantially one type of polarized beams when they pass through the selective phase plate 380. Since the shading plate 370 is placed on the incident side of the polarizing separation unit array 320 and the intermediate beams are thereby allowed to enter only the polarizing separation planes 331 in the polarizing separation units 330, few intermediate beams enter the polarizing separation planes 331 through the reflecting planes 332, and therefore, the polarized beams emitted from the polarizing separation unit array 320 are limited to substantially one type. Consequently, the illumination region 90 is illuminated substantially uniformly with substantially one type of polarized beams.

As described above, the polarizing illumination device 1 of this embodiment is advantageous in that randomly polarized beams emitted from the light source section 10 are converted into substantially one type of polarized beams by the polarized light generating device 20 that includes the first optical element 200 and the second optical element 300, and the illumination region 90 can be illuminated uniformly with the light beams polarized in the same direction. Moreover, since the process of generating the polarized beams accompanies little loss of light, almost all the light emitted from the light source section can be directed to the illumination region 90, which provides extremely high light use efficiency. Furthermore, since the shading plate 370 is placed in the second optical element 300, other beams polarized in a different direction rarely mix into polarized beams of the same type for illuminating the illumination region 90. Therefore, when the polarizing illumination device of the present invention is used as a device for illuminating a modulating device that produces a display using polarized beams such as a liquid crystal device, it is possible to obviate a polarizing plate which is conventionally placed on the side of the modulating device where the illumination light enters. Even if the polarizing plate is placed as is conventionally done, since the amount of light absorbed by the polarizing plate is extremely small, it is possible to substantially reduce the size of a cooling device that is needed to minimize heat generation of the polarizing plate and the modulation device. As mentioned above, the size of the condensed images 203 formed by the first optical element 200 is influenced by the parallelism of light beams that enter the first optical element (light beams emitted from the light source in the illumination device). When parallelism is low, since only a large condensed image can be formed, a large number of intermediate beams directly enter the reflecting planes without passing the polarizing separation planes in the polarizing separation units, and therefore, a phenomenon in which other beams polarized in a different direction mix into the illumination beams is inevitable. Accordingly, the structure of the polarizing illumination device of the present invention has a great effect, particularly in adopting a light source for emitting light beams having low parallelism in the apparatus.

In this embodiment, the condenser lens array 310, the shading plate 370, the polarizing separation unit array 320, the selective phase plate 380, and the emergent-side lens 390, which form the second optical element 300, are optically integrated, so that light losses caused at interfaces therebetween are reduced, and the light use efficiency is further enhanced. Although it is not always necessary to optically integrate these optical elements, it is preferable to optically integrate or fix the shading plate 370 on the light incident surface of the polarizing separation unit array 320 in order to effectively prevent other beams polarized in a



different direction from mixing into the illumination light. As a method of optically integrating the shading plate 370 with the light incident surface of the polarizing separation unit array 320, it is possible to stick the shading plate 370 to the light incident surface of the polarizing separation unit array 320 with an adhesive layer, or to directly form the shading surfaces 371 on the light incident surface of the polarizing separation unit array 320 as will be described later. On the other hand, as a method of fixing the shading plate 370 on the light incident surface of the polarizing separation unit array 320, it is possible to stick the peripheral portion of the shading plate 370 on the peripheral portion of the light incident surface of the polarizing separation unit array 320 by using a double-sided tape or similar device. In this situation, it is necessary to stick the entire peripheral portion of the shading plate 370, and the peripheral portion only has to be stuck at at least two points. In order to fix the shading plate 370 parallel with the light incident surface of the polarizing separation unit array 320, it is preferable to set the sticking points so that they are almost symmetrical with respect to the center point of the shading plate 370.

Furthermore, the beam splitting lenses 201 which form the first optical element 200 each extend laterally in accordance with the shape of the illumination region 90 like a laterally extended rectangle, and at the same time, two types of polarized beams emitted from the polarizing separation unit array 320 are separated in the lateral direction (the X-direction). This makes it possible to enhance illumination efficiency (light use efficiency) without wasting the light, even in illuminating the illumination region 90 which is shaped like a laterally extended rectangle.

In general, when light beams polarized in random directions are merely separated into P polarized beams and S polarized beams, the overall width of the separated beams doubles, which increases the size of the optical system. The polarizing illumination device of the present invention, however, forms a plurality of minute condensed images 203 through the first optical element 200, effectively uses the spaces produced in the formation process where no light exists, and respectively places the reflecting planes 332 of the polarizing separation units 330 in the spaces, thereby absorbing the lateral widening of the beams caused by the separation into two types of polarized beams. As a result, the overall width of the beams does not increase, and a compact optical system can be achieved.

First Modification of First Embodiment

In the first embodiment, the shading surfaces 371 that form the shading plate 370 may be replaced with reflecting planes for reflecting light in almost the opposite direction. That is, a reflecting plate 373 that includes a plurality of reflecting surfaces 374 and a plurality of open surfaces 375, as shown in FIG. 6, may be adopted instead of the shading plate 370 in the first embodiment. The reflecting surfaces 374 each can easily be formed of a dielectric multilayer film, a thin film made of metal having high reflectivity, such as silver or aluminum, or a combination thereof, and an extremely high reflectivity of more than ninety percent can be obtained depending on the type of the film. Even if the reflecting surfaces 374 are directly formed on the condenser lens array 310 or the polarizing separation unit array 320 shown in FIG. 1, similar functions are provided.

As opposed to the shading surfaces 371, the reflecting surfaces 374 hardly absorb light. Therefore, the adoption of the reflecting plate 373 can prevent peripheral optical elements from being thermally influenced by heat generation thereof. In addition, the light reflected by the reflecting

surfaces 374 and reflected by the parabolic reflector 102 placed in the light source section 10, can make enter again into the polarized light generating device 20 and lead into the open sections 375 of the reflecting plate 373. Then it is possible to efficiently use the light from the light source without waste.

Second Modification of First Embodiment

In the first embodiment, even if the shading surfaces for forming the shading plate are replaced with light diffusing surfaces for diffusing light, almost the same advantages as those obtained by the shading surfaces can be provided. That is, in the first embodiment, a light diffusing plate 376 that includes an arrangement of a plurality of light diffusing surfaces 377 and a plurality of open surfaces 378, as shown in FIG. 7, may be adopted instead of the shading plate 370. Since light incident on the light diffusing surface 377 is diffused, it is possible to substantially reduce the intensity of light that directly enters the reflecting plane without passing through the polarizing separation plane of the polarizing separation unit, and to effectively prevent a phenomenon in which other beams polarized in a different direction mix into illuminating beams including substantially the same type of polarized beams that are polarized in the same direction. Each light diffusing surface 377 can easily be realized by forming a light diffusing member on or inside a flat transparent substrate, making the surface of the transparent substrate uneven, or merely roughening the surface thereof. Even if the light diffusing surfaces 377 are directly formed on the condenser lens array 310 or the polarizing separation unit array 320 shown in FIG. 1, similar functions can be provided.

Adopting the light diffusing plate 376 makes it possible to reduce the costs compared with adopting the shading plate 370 and the reflecting plate 373 using dielectric multilayer films, metal thin films, or similar materials.

Third Modification of First Embodiment

Although the shading plate 370, the reflecting plate 373 and the light diffusing plate 376 in the first embodiment and the above-mentioned first and second modifications are each an optical element that is physically independent from the condenser lens array 310 and the polarizing separation unit array 320 located in front and in the rear thereof, even if the shading surfaces 371 for forming the shading plate 370, the reflecting surfaces 374 for forming the reflecting plate 373, or the light diffusing surfaces 377 for forming the light diffusing plate 376 are directly formed on the light incident surfaces of the polarizing separation units 330 for forming the polarizing separation unit array 320, the same advantages as those obtained in the use of these optical elements can be obtained.

This modification will be specifically described with reference to FIG. 8. In a polarizing separation unit array 320A whose outward appearance is shown in FIG. 8, shading surfaces 321 are directly formed on light incident surfaces of polarizing separation units 330A which form the polarizing separation unit array 320A, and regions 322 where no shading surfaces are formed correspond to the open surfaces 372 of the above-mentioned shading plate 370 for transmitting light therethrough. When the polarizing separation unit array 320A having the shading surfaces 321 directly formed thereon is used as in this modification, since there is no need to use the shading plate 370 as a physically independent optical element, it is possible to reduce the size and cost of the second optical element. Of course, reflecting surfaces or light diffusing surfaces may be directly formed on the polarizing separation units 330A instead of the shading surfaces 321, and this situation provides the same advantages as those of this modification.



Fourth Modification of First Embodiment

Although the shading plate 370, the reflecting plate 373 and the light diffusing plate 376 in the first embodiment and the above-mentioned first and second modifications are each an optical element that is physically independent from the condenser lens array 310 and the polarizing separation unit array 320 located in front and in the rear thereof, even if the shading surfaces 371 for forming the shading plate 370, the reflecting surfaces 373 for forming the reflecting plate 373, or the light diffusing surfaces 374 for forming the light diffusing plate 376 are directly formed on the condenser lenses 311 for forming the condenser lens array 310, the same advantages as those in the use of these optical elements can be obtained.

This modification will be specifically described with reference to FIG. 9. In a condenser lens array 310A whose outward appearance is shown in FIG. 9, shading surfaces 312 are directly formed on surfaces of condenser lenses 311A for forming the condenser lens array 310A from which light is emitted, and regions 313 where no shading surfaces are formed correspond to the open surfaces 372 of the above-mentioned shading plate 370 for transmitting light therethrough. When the condenser lens array 310A having the shading surfaces 312 directly formed thereon is used as in this modification, since there is no need to use the shading plate 370 as a physically independent optical element, it is possible to reduce the size and cost of the second optical element. Of course, reflecting surfaces or light diffusing surfaces may be directly formed on the condenser lenses 311A instead of the shading surfaces 312 of this modification, and this case provides the same advantages as those of this modification. In this modification, if the condenser lens array 310A is placed spatially apart from the polarizing separation unit array and the selective phase plate that are other optical elements for forming the second optical element, it is possible to prevent the optical elements from being influenced by heat generation resulting from light absorption by the shading surfaces, the reflecting surfaces, and the light diffusing surfaces.

Fifth Modification of First Embodiment

Although a flat transparent member like a glass plate is partially provided with opaque films made of chrome, aluminum, or similar material in the shading plate 370 of the first embodiment, an opaque flat plate such as an aluminum plate may be provided with open sections.

This modification will be specifically described with reference to FIG. 10. In a shading plate 370A whose outward appearance is shown in FIG. 10, an opaque flat plate 371A is provided with open sections 372A. When the shading plate 370A is fixed on the light incident surface of the polarizing separation unit array 320 in order to effectively prevent other beams polarized in a different direction from mixing into the illumination light, two sticking points 379*a* and 379*b* on the peripheral section of the shading plate 371A are fixed on the light incident surface of the polarizing separation unit array 320 with double-sided tapes. Since the sticking points 379*a* and 379*b* are positioned so that they are almost symmetrical with respect to the center point of the shading plate 370A, the shading plate 370A is allowed to be fixed in parallel with the light incident surface of the polarizing separation unit array 320.

When the shading plate 370A having the opaque flat plate 371A, such as an aluminum plate, provided with the open sections 372A is used as in this modification, it is possible

to reduce the costs compared with the shading plate 370 in which a flat transparent member, such as a glass plate, is partially provided with opaque films made of chrome, aluminum, or similar material.

## Second Embodiment

A description will be given of a direct-view display apparatus in which the polarizing illumination device 1 of the first embodiment is incorporated. In this embodiment, a transmission-type liquid crystal device is used as a modulating device for modulating light beams emitted from the polarizing illumination device according to display information.

FIG. 11 is a schematic structural view showing the principal part of an optical system of a display apparatus 2 according to this embodiment, and shows the sectional structure in the XZ plane. The display apparatus 2 of this embodiment roughly comprises the polarizing illumination device 1 shown described in the first embodiment, a reflecting mirror 510, and a liquid crystal device 520.

The polarizing illumination device 1 has a light source section 10 for emitting randomly polarized beams in one direction, and the randomly polarized beams emitted from the light source section 10 are converted into substantially the same type of polarized beams by a polarized light generating device 20. The reflecting mirror 510 turns the light travelling direction of the polarized beams emitted from the polarizing illumination device 1 by about 90°. The liquid crystal device 520 is illuminated with substantially the same type of polarized beams. Polarizing plates 521 are placed in front of and behind the liquid crystal device 520. A light diffusing plate (not shown) may be placed before the liquid crystal device 520 (on the side of the reflecting mirror 510) for the purpose of improving the angle of view.

The display apparatus 2 having such a structure employs a liquid crystal device for modulating the same type of polarized beams. Therefore, if randomly polarized beams are directed to the liquid crystal device by using a conventional illumination device, about half the randomly polarized beams are absorbed by the polarizing plates 521 and turned into heat, whereby the light use efficiency is low. The display apparatus 2 of this embodiment, however, substantially improves such a problem.

In the polarizing illumination device 1 of the display apparatus 2 according to this embodiment, only one type of polarized beams, for example, P polarized beams, are subjected to a rotatory polarization action by the $\lambda/2$ phase plate, and the polarization direction thereof is made identical with that of the other type of polarized beams, for example, S polarized beams. Since substantially the same type of polarized beams, which are polarized in the same direction, are directed to the liquid crystal device 520, the amount of light to be absorbed by the polarizing plates 521 is extremely small, which makes it possible to enhance the use efficiency of the source light, and to thereby obtain a bright display state.

Particularly, in the polarizing illumination device 1 used as an illumination device, since the shading plate 370 is placed inside the second optical element 300, other polarized beams which are unnecessary for display on the liquid crystal device rarely mix into the illumination light emitted from the polarizing illumination device 1. As a result, the amount of light absorbed by the polarizing plate 521 placed on the light incident side of the liquid crystal device 520 is extremely small, and therefore, the amount of heat generated in light absorption is extremely small. Consequently, it is



possible to omit a cooling device for minimizing the increase in temperature of the polarizing plate 521 and the liquid crystal device 520, or to substantially reduce the size of the cooling device even if such omission is impossible.

## Third Embodiment

A description will be given of a first example of a projection display apparatus in which the polarizing illumination device 1 described in the first embodiment is incorporated. In this embodiment, a transmission-type liquid crystal device is used as a modulating device for modulating light beams emitted from the polarizing illumination device according to display information.

FIG. 12 is a schematic structural view showing the principal part of an optical system of a projection display apparatus 3 according to this embodiment, and shows the sectional structure in the XZ plane. The projection display apparatus 3 of this embodiment generally comprises the polarizing illumination device 1 described in the first embodiment, a colored light separating means for separating a white light beam into three colored lights, three transmission-type liquid crystal devices for modulating the colored lights according to display information and thereby forming display images, a colored light synthesizing means for forming a color image by synthesizing the three colored lights, and a projection optical system for projecting and displaying the color image.

The polarizing illumination device 1 of this embodiment has a light source section 10 for emitting randomly polarized beams in one direction, and the randomly polarized beams emitted from the light source section 10 are converted into substantially the same type of polarized beams by a polarized light generating device 20.

First, the red light of the light emitted from the polarizing illumination device 1 transmits through a blue-green reflecting dichroic mirror 401 serving as the colored light separating means, and the blue light and the green light are reflected. The red light is reflected by a reflecting mirror 403 and reaches a liquid crystal device 411 for red light. On the other hand, the green light of the blue and green lights is reflected by a green reflecting dichroic mirror 402 that also serves as the colored light separating means, and reaches a liquid crystal device 412 for green light.

Since the blue light has the longest optical path of the colored lights, a light guide means 430 formed of a relay lens system comprising an incident lens 431, a relay lens 432, and an emergent lens 433 is provided for the blue light. That is, after transmitting through the green reflecting dichroic mirror 402 and the incident lens 431, the blue light is first reflected by a reflecting mirror 435, and directed to and focused onto the relay lens 432. After being focused onto the relay lens, the blue light is directed to the emergent lens 433 by a reflecting mirror 436, and then, reaches a liquid crystal device 413 for blue light. The liquid crystal devices 411, 412, and 413 located at three positions respectively modulate the colored lights so that the colored lights contain corresponding image information, and make the modulated colored lights enter a crossed dichroic prism 450 serving as the colored light synthesizing means. The crossed dichroic prism 450 includes a dielectric multilayer film for reflecting red light and a dielectric multilayer film for reflecting blue light which are crossed in the form of X, and synthesizes the modulated light beams, thereby forming a color image. The color image formed therein is enlarged and projected onto a screen 470 by a projection lens 460 serving as the projection optical system, so that a projection image is formed.

The projection display apparatus 3 having such a structure employs the liquid crystal devices each for modulating one type of polarized beam. Therefore, if randomly polarized beams are directed to the liquid crystal device by using a conventional illumination device, about half of them are absorbed by a polarizing plate (not shown) and turned into heat. Therefore, the light use efficiency is low, and there is a need for a large and noisy cooling device for minimizing heat generation of the polarizing plate. The projection display apparatus 3 of this embodiment, however, substantially improves such problems.

In the polarizing illumination device 1 of the projection display apparatus 3 according to this embodiment, only one type of polarized beam, for example, a P polarized beam is subjected to the rotatory polarization action by a $\lambda/2$ phase plate, and the polarization direction thereof is made identical with that of the other type of polarized beam, for example, an S polarized beam. Since substantially the same type of polarized beams, which are polarized in the same direction, are directed to the liquid crystal devices **411**, **412**, and **413** located at three positions, the amount of light to be absorbed by the polarizing plate is extremely small, which makes it possible to enhance the light use efficiency, and to thereby obtain a bright projection image.

Particularly, in the polarizing illumination device 1 used as an illumination device, since the shading plate **370** is placed inside the second optical element **300**, other polarized beams which are unnecessary for display on the liquid crystal device rarely mix into the illumination light emitted from the polarizing illumination device 1. As a result, the amount of light absorbed by polarizing plates (not shown) respectively placed on the light incident sides of the liquid crystal devices **411**, **412**, and **413** located at three positions is extremely small, and therefore, the amount of heat generated in light absorption is extremely small. Consequently, it is possible to substantially reduce the size of a cooling device for minimizing the increase in temperature of the polarizing plates and the liquid crystal devices. As mentioned above, a small cooling device will do for a projection display apparatus capable of displaying a considerably bright projection image with a considerably high-power light source lamp, which makes it possible to reduce noise of the cooling device, and to thereby achieve a quiet and high-performance projection display apparatus.

Furthermore, the polarizing illumination device 1 spatially separates two types of polarized beams in the lateral direction (the X direction) by the second optical element **300**. Therefore, the polarizing illumination device 1 does not waste the light, and is convenient for illuminating a liquid crystal device shaped like a laterally extended rectangle.

As described in connection with the above described first embodiment, the widening of light beams emitted from the polarizing separation unit array **320** is restricted although the polarizing illumination device 1 of this embodiment incorporates polarizing conversion optical elements therein. This means that minimal light enters the liquid crystal device at a large angle in illuminating the liquid crystal device. Accordingly, it is possible to achieve a bright projection image without using a projection lens system having a small F-number and an extremely large aperture, and to thereby achieve a compact projection display apparatus.

Since the crossed dichroic prism **450** is used as the colored light synthesizing means in this embodiment, it is possible to reduce the size of the apparatus. Furthermore, since the optical paths between the liquid crystal devices **411**, **412**, and **413**, and the projection lens system are short, even if the projection lens system has a relatively small aperture, it is possible to achieve a bright projection image. Still furthermore, though only one of the three optical paths of the colored lights is different in length from the others, since the light guide means **430** formed of a relay lens system comprising the incident lens **431**, the relay lens **432**, and the emergent lens **433** is provided for the blue light having the longest optical path, no color inconsistency arises.

The projection display apparatus may comprise a mirror optical system using two dichroic mirrors as the colored light synthesizing means. Of course, it is also possible in that case to incorporate the polarizing illumination device of this embodiment, and to form a high-quality bright projection image having a high light use efficiency, similarly to this embodiment.

## Fourth Embodiment

Another embodiment of a projection display apparatus in which the polarizing illumination device 1 described in the first embodiment is incorporated will be described. In this embodiment, reflection-type liquid crystal devices are used as modulating devices for modulating light beams emitted from the polarizing illumination device according to display information.

FIG. 13 is a schematic structural plan view of the principal part of an optical system in a projection display apparatus 4 of this embodiment. The projection display apparatus 4 of this embodiment generally comprises the polarizing illumination device 1 of the first embodiment, a polarizing beam splitter **480**, a crossed dichroic prism **450** doubling as the colored light separation means and the colored light synthesizing means, three reflection-type liquid crystal devices **414**, **415**, and **416** serving as modulating devices, and a projection lens **460** serving as the projection optical system.

The polarizing illumination device 1 has a light source section **10** for emitting randomly polarized beams in one direction, and the randomly polarized beams emitted from the light source section **10** are converted into substantially the same type of polarized beams (S polarized beams in this embodiment) by a polarized light generating device **20**.

The light beams emitted from the polarizing illumination device 1 enter into the polarizing beam splitter **480**, and are reflected by a polarizing separation plane **481**. Then, the traveling direction of the light beams is changed by approximately 90°. Then, the light beams enter the adjoining crossed dichroic prism **450**. Although most of the light beams emitted from the polarizing illumination device 1 are S polarized beams, a few polarized beams polarized in a different direction from the S polarized beams (P polarized beams in this embodiment) sometimes mix, and the light beams polarized in the different direction (the P polarized beams) transmit through the polarizing separation plane **481** unchanged, and are emitted from the polarizing beam splitter **480** (these P polarized beams do not serve as illumination light for illuminating the liquid crystal devices.)

The S polarized beams that are incident on the crossed dichroic prism **450** are separated into three light beams of red, green, and blue by the crossed dichroic prism **450** in accordance with the wavelength, and the light beams respectively reach the reflection liquid crystal device **414** for red light, the reflection liquid crystal device **415** for green light, and the reflection liquid crystal device **416** for blue light, thereby illuminating the liquid crystal devices. That is, the crossed dichroic prism **450** acts as the colored light separa-